IASDR 2019

International Association of Societies of
Design Research Conference 2019
DESIGN REVOLUTIONS

Manchester School of Art
Manchester Metropolitan University
02-05 September 2019

Unblocking the Circular Economy

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There is a blockage in the Circular Economy. Discarded plastic products end up in the Indian Ocean where thousands of tonnes of waste plastic is washed up on the beaches of East Africa. This creates a detrimental impact on both the marine ecosystem and the economy where the locals rely on coastal fishing, trade and tourism for their livelihoods.

Plastic comes ashore in many forms and is badly degraded by the elements such that when processed locally, the quality of the recycled material cannot meet the needs of the community. The researchers worked with shoreline communities to help develop a processing method capable of giving waste plastic a valuable second life. As a demonstration of the potential of this new recycled material they constructed a traditional dhow sailing boat entirely from plastic trash collected from Kenya's beaches and towns. During its 500 kilometre maiden voyage from Lamu in Kenya to Zanzibar in Tanzania, the researchers stopped at communities along the way to change mindsets about plastic waste.

This paper practically demonstrates how an environmentally and economically damaging waste problem can be re envisaged as a valuable resource that supports the local and regional economy and unblocks the circular economy in the shoreline communities of East Africa.

Keywords: Circular economy; design innovation; dhow; plastic recycling.

1 Introduction

Annually, thousands of tonnes of plastic products are discarded and end up the Indian Ocean. Plastic waste is washed up on the beaches of Kenya in East Africa. This impacts detrimentally on both the marine ecosystem and the economy of the country where the locals rely on coastal fishing, trade and tourism for their livelihoods.

This case study that demonstrates how, a group of people, were able to unblock the Circular Economy in Kenya by building a dhow.

Figure 1. The Flipflopi during a beach event in Diani Kenya!

Appalled by the volume of waste plastic he found on the deserted beaches of Kenya, project visionary Ben Morrison decided to turn the trash that had been washed up into something useful that could communicate the importance of keeping our oceans free from single use plastics to a global audience.

1.1 The Marine Plastic Problem

The Indian Ocean is surrounded by some of the most prolific contributors to marine pollution on the planet and the currents in action in the Indian Ocean deliver waste onto the shores of East Africa.

It is estimated that 5 countries, China, Indonesia, the Philippines, Thailand, and Vietnam dump more than half of all ocean plastic waste that originates from the land (Ocean Conservancy, 2015).

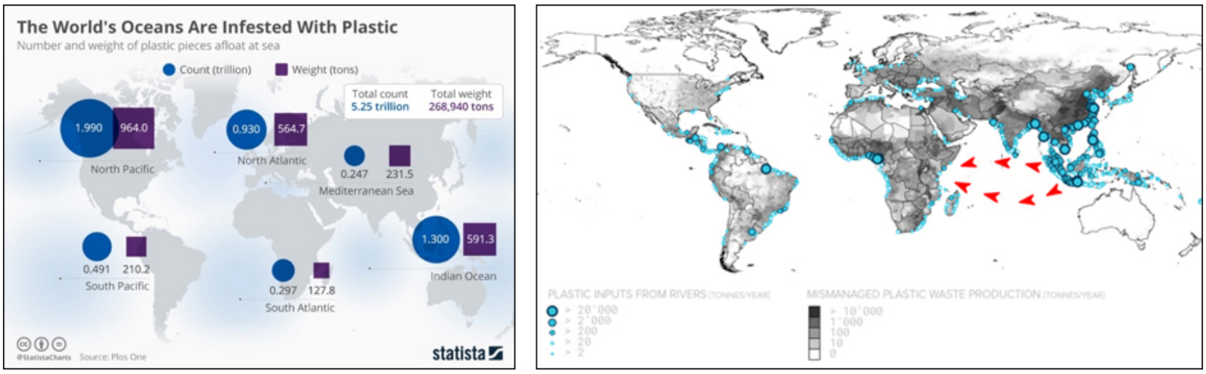

Figure 2. The main contributors to marine pollution, hotspots of river based waste and red arrows depicting the Indian Ocean currents that drive waste onto the East African coast from Asia.

It is estimated that over 12.7 million metric tons of plastic (Jambeck, 2015) enter the oceans each year, this originates mainly inland but then flows into the rivers and then out to sea. Between 88% and 95% (Schmidt, 2017) of this waste emanates from ten rivers, eight can be found in Asia and two in Africa. It has been estimated that there is almost 60,000 tons of plastic floating in the Indian Ocean alone (Eriksen, 2014). Plastic waste is a major problem for marine life, it can be ingested and lager animals can become entangled in it. Larger pieces are broken down into smaller particles that can then leach toxic chemicals into the sea. In 2010 a massive marine plastic waste patch was discovered in the Indian Ocean (Parker, 2014) measuring roughly 2 million miles^2 (about 5 million km^2), this is continuing to grow!

The number of people who depend on the oceans as their primary source of protein is increasing, fish represents almost 20% of the average intake of protein (per capita) for about 3.2 billion people worldwide as reported by the Food and Agriculture Organization of the United Nations (FAO, 2018). Contamination of the sea and marine life has a direct effect on the people who live on this coastal communities.

Only nine per cent of the nine billion tonnes of plastic the world has ever produced has been recycled. The overwhelming majority of plastics, including plastic drinking bottles, plastic bottle caps, food wrappers, plastic grocery bags, plastic lids, straws and stirrers, and foam takeaway containers, are designed to be thrown away after a single use, ultimately ending up in our environment.

Some key facts:

- A single plastic bottle can almost 450 years (NOAA, 2019) or more to degrade.
- Over 12.7 million metric tons of plastic enters the ocean every year. The ocean is expected to contain (MacArthur, 2016) 1 tonne of plastic for every 3 tonnes of fish by 2025, and by 2050, more plastics than fish (by weight).
- Only 9% of the 8.3 billion tonnes of plastic the world has ever produced has been recycled (Economist, 2018).

This global problem can be simply illustrated in Kenya. In November 2016, 35 tonnes of plastic was collected from a 10km beach in Lamu in Northern Kenya. In a one 3 hour beach clean-up that was organised locally by the community, 5.8 tonnes of plastic was cleaned up and they had to stop because the sun was too hot.

This has a detrimental effect on the economy of the country, especially Kenya where its biggest natural asset is its environment.

1.2 The impact of ocean waste in Kenya

The plastic that litters the shores of Kenya has reached the end of its life and has no direct use. This impacts detrimentally on both the local marine ecosystem and the economy of Kenya where the locals rely on coastal fishing, trade and tourism for their livelihoods.

- Politically Kenya is a leading nation in the fight against marine pollution, in August 2017 it was the first county in the world to ban the use of single use plastic bags.
- The plastic on the beaches is affecting the local communities reducing the amount of fish they can catch.
- One example highlights the way that pollution enters the food chain, this is called bioaccumulation, tiny plastic particles are ingested by plankton that is then consumed by the fish that are eaten by the people who live on the coast.
- Larger pieces of plastic are eaten by larger marine animals and entanglement is also an issue.
- Casper van de Geer, a project manager with the Local Ocean Trust, a Watamu organization states that “in polluted beaches, turtles have to dig through the marine debris to lay eggs. Hatchlings get stuck in the debris when they hatch. Once they escape and swim into the middle of the ocean, only to find heaps of mixed plastics, netting and other debris”. (Mbugua, 2018)
- Ali Skanda (The Flipflopi Chief Boat Builder) reports that the local fishermen often catch more plastic in their fishing nets than actual fish.

Plastic waste comes ashore in many forms and is badly degraded by the elements such that when processed locally, the quality of the recycled material resembles the consistency of a Crunchy bar. This low-grade recycled material is not strong enough to meet most functional needs of the community.

1.3 There is a block in the Circular Economy

The majority of the plastic that reaches the shores of Kenya is unusable, it cannot be maintained, reused or refurbished. These are key factors governing the Circular Economy, the final option open to the locals is to recycle the material, this this is expensive as the plastic is badly degraded due to environmental factors such as UV radiation.

Waste plastic is collected from the coast but there are currently limited options for recycling. Watamu Marine Association works with EcoWorld Watama to organise beach clean-ups, they use the plastic found on the beach to create small pieces of art that can be sold back to the tourists but this only accounts for a very small amount of plastic that can be recycled. The beach clean-ups in Lamu for example have created a 60 tonne pile of plastic that cannot be recycled using existing techniques that EcoWorld Watama could offer.

There is a blockage in the circular economy and tonnes of plastic waste is piling up behind it. However, as the flow of material is linier, the aim of this research is to remove the block so that recycled material can flow back into the system.

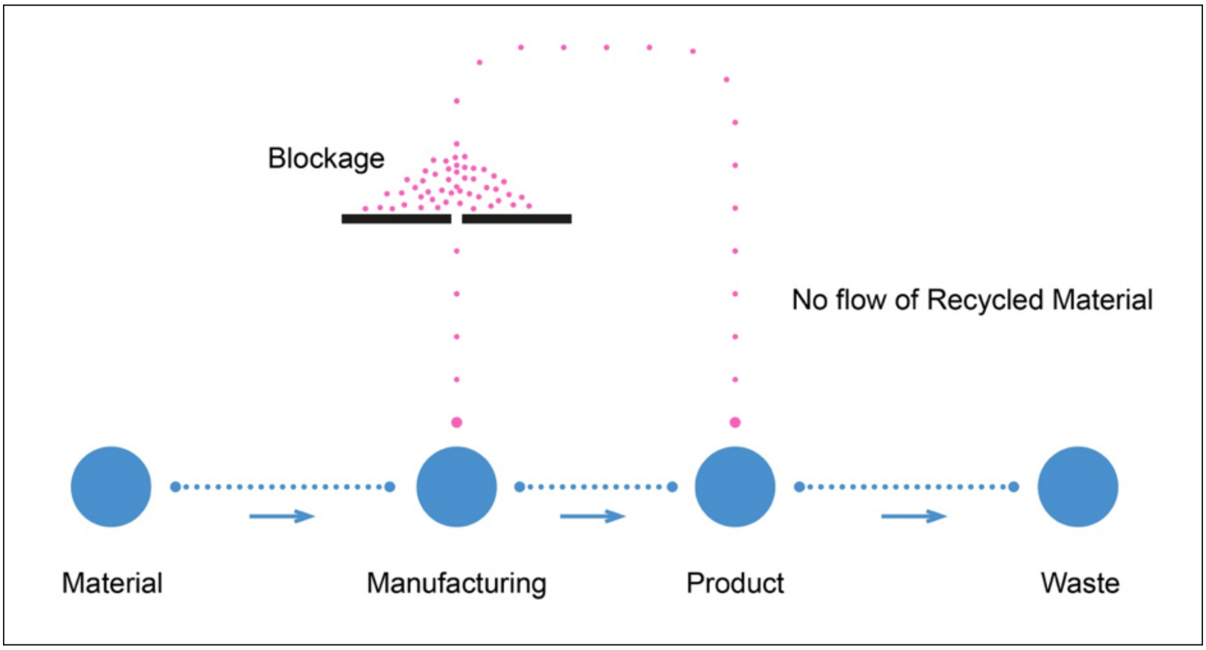

Figure 3. The Blockage in the Circular Economy.

1.4 Turning waste plastic into something useful

Shoreline communities are keen to find solutions to the problems of plastic waste and are constantly looking for ways to turn it into something viably useful that can help their communities and local economy. However when processed locally, the quality of the recycled, material is not good enough to be used to manufacture durable products that give the plastic a second life! This means that recycled products tend to be limited to large, less refined structures.

Some good recycling options exist in the construction industry (Shini, 2018):

- Roofing Tiles: Lighter material, easier, quicker installation and a lower carbon footprint.
- Concrete: Recently studies (Schaefer, 2018) show that by adding recycled plastic to cement they can get a stronger and more resilient material.
- Indoor Insulation: Easy installation, durability and long-term energy saving.
- Structural Lumber: Picnic tables and benches, no need for preservatives and great durability.
- PVC Windows: Longer lifetime (up to 40 years), there is a surplus of production material and the same insulation quality as regular plastic.
- Bricks: Bricks can be moulded like LEGO making the construction process much quicker, it can also be made fire-resistant and is cheaper and eco-friendly.
- Fencing: Offers longevity, durability and there is no need for paint as the colour can be added in during recycling process.

All these materials can be produced locally but to a much lower tolerance than is possible in more developed counties that can invest in more expense machinery.

1.5 Challenging the community to produce high quality recycled material by building a sailing dhow

There is a demand for boats to be manufactured all along the coastline of East Africa, for fishing, trade and tourism. Dhow's have been used throughout this part of the world for thousands of years, traditionally they are manufactured from Teak, Mahogany and Mango.

These materials are becoming harder to acquire so new materials are required to be used in the manufacture of these boats.

Recycled plastic can meet this need as traditional craftsmen can use it in very much the same way as they have been making boats for years. Good quality recycled plastic also has the added benefits found in the construction industry, such as longevity, durability ultimately, a longer lifespan, especially when used in the harsh environments found in the oceans.

2 Recycling materials to make a dhow

To put this paper in context, it is important to understand how dhows are constructed. Dhow construction techniques are thousands of years old and the dhow is one of the first designs of boat that helped humans trade across large expanses of water.

Traditionally they have Lateen sails that were developed by the Romans to be able to tack into the wind, this was a radical improvement on previous sail technology. They are predominantly found in the Persian Gulf, East Africa, Yemen and the coastal areas of South Asia including Pakistan, India and Bangladesh (Dhow, 2018).

2.1 Traditional dhow building methods

Traditionally the process of constructing a dhow involves the following stages:

- The boat builder lays the keel, which is made from a hardwood such as Teak or Mahogany.
- Ribs are attached to the keel, these are often made from Mango, craftsmen use the naturally occurring twists in the mango to create the bends in the ribs.
- Strakes are attached to the outside of the ribs, these are the flat planks of wood, between 5 and 15 feet long, butted end to end with tongue and groove joints.
- Everything is then tied together, this is done using coir string and rope which are called Pythons.
- The rudder and top deck is made from Teak or Mahogany.

The mast was traditionally made from Teak or Coconut and coir or sisal was used for the rope. Sails were made from Palm Leaves stitched together, more latterly they are made from a heavy-duty cotton like canvas which is between 400 – 500 grams/m^2. This construction method is still used today on the coast of Kenya.

2.2 Creating the plastic components

The core aim of this research was to find simple methods to construct a dhow using traditional craft techniques that have been developed over thousands of years and that are common methods found up and down the East African coast.

Everything was to be made locally in Kenya so the big challenge was to find collaborators with recycling facilities who could deliver quality materials, reliably! This was crucial for the production of the main components, the keel, the ribs, the rudder, the strakes and the decking.

Regeneration Africa in Malindi, was the closest plastic recycling manufacturer (200km) from the boatbuilding workspace in Lamu. Their business is focussed on the production of fencing posts and tiles used in the construction industry locally.

Initially they mixed all types of plastic (PET, PP, HDPE and LDPE) and sand into their products to make them harder and cheaper, which for building products is great.

Figure 4. Poor quality plastic, holes the sizes of Mangos and Oranges!

The initial results we received from Regeneration Africa however were not fit for purpose, the parts were heavy and stiff and not suitable for the application. There was also one additional major issue with this material, when the plastic was moulded into larger pieces, the moulding process produced huge air pockets, the size of mangos and oranges. When the boatbuilders used this material, huge holes appeared in the plastic rendering it unusable.

3 Testing and evaluation

The researchers needed to find out whether it would be possible to produce high enough quality material from the waste plastic found on Kenyan beaches and fit for the purpose of building a dhow.

The first challenge was to eliminate the presence of large bubbles in the recycled material, this needed to be addressed to create high quality parts using low-tech machinery.

3.1 Northumbria University testing – Stage 1

The researchers tested samples of the low-quality material using the following method.

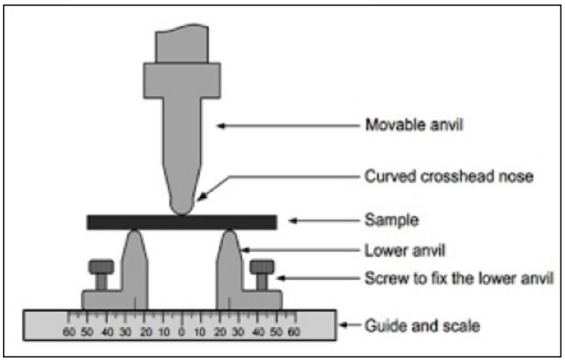

Figure 5. Images of testing at Northumbria University.

A rig was constructed using a simple three-point bending configuration; this allowed the flexural strength of a sample to be tested by measuring the applied force against deflection.

The equipment used for this experiment consisted an Instron 3300 Floor Model Universal Testing System, which was linked up to and interpreted using Instron Bluehill 2 Software.

The samples that were tested were all of the same dimension (300.00mm long, 28.00mm wide and 38.00mm tall) and they were evaluated against similar materials with known physical characteristics used in the construction of dhows.

	Yield Load (kN)	**Displacement** (mm)	**Flexural Strength** (MPa)
Hardwood	**7.550**	**11.21**	**70.02**
Softwood	**5.043**	**14.10**	**46.78**
Recycled Plastic Sample 1	**1.305**	**5.93**	**12.10**
Recycled Plastic Sample 2	**1.245**	**7.01**	**11.55**

Table 1. Results of sample testing.

The materials tested were significantly below the Flexural Strength required. The main reason as identified prior to the testing was the presence of the air pockets within the recycled material. The failures always originated from the holes that allowed cracks to permeate through the material.

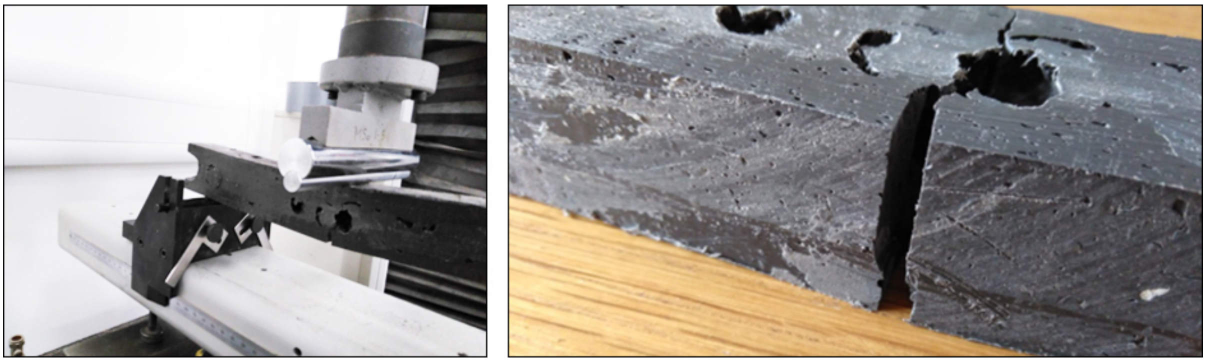

Figure 6. Cracks permeating through the sample material.

It was important to reduce the overall number of holes, but also to eliminate holes with sharp corners that caused stress concentration ultimately leading to failure in the material. This is the same characteristic that leads aircraft to have rounded windows. The bubbles and holes with sharp sides (shear) are caused from oil-based impurities within the material, the holes originate from outgassing of the molten plastic when cooling, containing humidity, the oil-based impurities come from the remaining waste particles within the plastic (paper, organics, wrappers, colour).

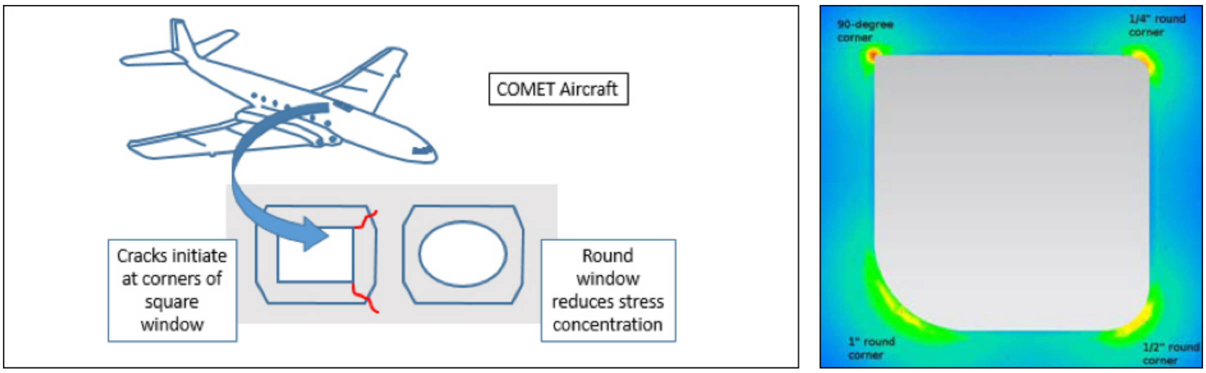

Figure 7. Square windows on planes were changed to round to reduce failure.

Another issue was the inconsistency of the material, it was heterogeneous and therefore the plastic tended to cool at different rates during the casting process. There were clear definitions between these areas causing skins to appear within the material and in doing so, creating areas of weakness. If the cooling of the material could be controlled then this would help with the overall strength of the material post production.

If the manufacturing process could be refined so that the consistency of the material could be made more homogenous (consistent) and the holes and bubbles significantly reduced then the Flexural Strength of the material could be increased substantially.

3.2 Processing recommendations

Observation and testing revealed that three aspects of the recycling process that needed to be addressed to reduce the shape, frequency and size of the air bubbles and increase the quality of the material:

1. **Sorting:** Sorting of different plastics so that similar polymers are used together.
2. **Cleaning/Drying:** Cleaning and drying of the plastic prior to melting to remove any impurities that cause the sharp air bubbles to appear.
3. **Casting:** Application of heat and pressure to create small regular air bubbles.

4 A refined process of recycling the waste

The researchers went about improving the recycling process by adding pre-sorting, cleaning and drying stages prior to melting the material, they also increased the pressure when the molten plastic was poured into the moulds and added heat to the outside of the moulds to get better consistency when the material cooled.

4.1 Pre-Sorting

Together with Regeneration Africa, the production methods were modified to use only a single type of plastic, Polyethylene. This plastic type could be easily identified though a very basic appreciation of production methods, in Kenya, PE and HDPE are blow moulded, lots of it washes up on the beaches and it can be easily sorted. The plastic that was collected was then shredded into small pieces before progressing to the next stage.

4.2 Cleaning and drying

The cleaning and drying process was highly controlled, initially the shredded plastic was washed, and rinsed thoroughly, it was then dried prior to being melted. This process was fundamental as it removed the organic and oil-based impurities that were still present in the waste plastic when collected.

Any organic and oil-based based impurities left within the plastic when it is melted are the main cause of holes and importantly holes with sharp corners in the finished material. The removal and control of such holes is fundamental in the production of consistent material with good mechanical properties for use in this context.

4.3 Casting

The molten liquid plastic is poured into moulds which are made from steel sheets that are welded together into shape to create each casting. When each mould is full of plastic, a top plate is put into position and pressed down with car jacks so that the material is held under pressure during cooling. The outside of the moulds are pre-heated and then cooled, this allows for a controlled cooling of the material throughout, any air bubbles left within the mould are also contained and are small and round with no sharp corners. This process creates uniform components with a high level of material consistency.

Figure 8. Images of sorting and the moulds used in the construction of the components.

5 The Results

By simple modification of processing methods, the researchers found that significantly higher quality material could be consistently produced. Because of it's Flexural Strength this higher grade recycled plastic material offers a wider range of valuable applications than were previously possible. This is helping to create greater demand for recycled plastic which because of its characteristics is sometimes the material of choice.

5.1 Material testing – Stage 2

The researchers carried out a second stage of testing using the new higher quality material at Northumbria University in May 2018. The results of the first tests in May 2017 gave baseline results of approximately 12.00MPa. The results from the second test provided results of up to 24.80MPa, an increase of over 100% in the Flexural Modulus of the recycled material. This meant that the researchers had succeeded in producing a recycled material fit for the construction of a sailing dhow.

Figure 9 shows that when the blockage is removed, the plastic material can flow back into the circular economy system instead of ending up as waste as was shown in figure 3.

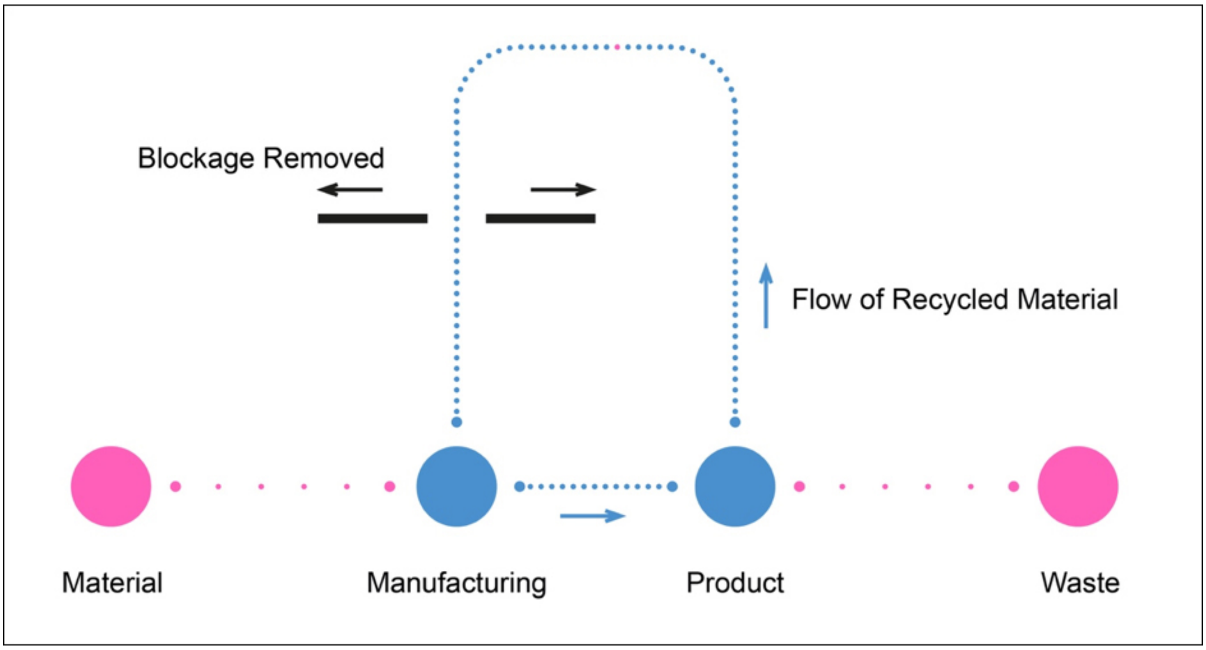

Figure 9. Unblocking in the Circular Economy.

Three technical challenges were solved and when used in combination, created a stable and suitable material for dhow manufacture, the three processes, when used locally in combination included:

1. **Sorting:** Careful sorting of the different plastics so that similar polymers were used together.
2. **Cleaning/Drying:** Cleaning and drying of the plastic prior to melting.
3. **Casting:** Control of heat and pressure to create structurally sound pieces of plastic.

5.2 The implementation, putting the materials into practice

The parts that were cast from the moulds were designed to be oversized, Ali Skanda (The Chief Boat Builder) and his team then used simple tools to craft the main moulded components (the keel, the ribs, the rudder, the strakes and the decking) into pieces that then were able to be fitted together.

Different moulds were produced for the keel, rudder and 6 different sized ribs (a number of boat ribs are produced from the same mould and the left and right sides are identical). There is also just one mould for the strakes as they are uniform and can be cut down to size during the final construction.

The integrity of the boat comes from the interlocking of the different components. Important areas were reinforced using stainless steel bolts, other components were made larger (thicker and wider) to compensate for this new material and its reduced mechanical strength when compared to wood.

The overall shape of the finished dhow was conventional but with a modified stern that helped with the stability of the vessel.

Figure 10. Images of the build process showing the internal structure.

Ribs were fitted to the main keel to create the skeleton of the dhow and over this were attached the strakes. To seal the hull, the dhow was filled with water, Ali and the construction team identified holes in the structure where the water leaked out. These holes were plugged with a mixture of cotton and tar which made the whole dhow watertight.

5.3 The Flip-Flop skin

The final process in the building of the Flipflopi Dogo was to make it look eye catching, this was done with the application of over 30,000 flip-flops collected from the beaches in Kenya. A local artist, Benson Gitari and his team sorted thousands of flip-flops, cut them up into regular sized pieces and glued them together to create large panels, which were then applied to the outer hull of the dhow.

Figure 11. Images of the flipflop outer skin attached to the hull.

5.4 Seaworthiness

The Flipflopi gained seaworthiness approval from the following regulatory bodies:

- Kenya Maritime Authority,
- Kenya Ports Authority,
- Tanzania Maritime Authority and
- The Tanzania Ports Authority.

6 Impact of the research

The Flipflopi project team has pioneered new techniques to craft the various components used in the construction of the dhow. Every single element of the boat was constructed by hand and the dhow was finally clad in colourful sheets of recycled flipflops collected during beach clean-ups on Lamu's beaches.

For hundreds of years Mangrove wood has been used to craft the ribs of sailing dhows however this material is now banned globally because of damage to the vast and varied natural habitats created by mangroves.

Through this research project a new high grade, locally produced recycled plastic is providing a sustainable alternative to the traditional materials used in dhow building. This high-grade recycled plastic is a good substitute for the wood of the Mangrove tree, it brings with it many additional properties and offers a valuable second (and hopefully longer) life for waste plastic that would otherwise litter the shores of East Africa.

7 The Flipflopi Expedition Project impact

Through the building of the dhow using recycled plastic, the project was able to create the following impact during its first expedition:

- The dhow was launched in late 2018 in Lamu and the Project partnered with UN Environment's Clean Seas campaign, which engages governments, the public and the private sector in the fight against marine plastic pollution.
- The partnership of the Flipflopi Project with the UN Environment was key to enable them to engage international decision makers on the environment to activate real change beyond the expedition.
- The 16 strong expedition team travelled 500km in two weeks from Lamu (Kenya) to Zanzibar (Tanzania) at the end of January 2019. They stopped at 12 different coastal communities en route and communicated their message to over 10,000 that met them on the beaches including over 3,000 schoolchildren and 50 local conservation and ecotourism organisations.
- During the two-week voyage, they reached a worldwide audience of over 850 million via media coverage and appeared in over 200 media articles and features in over 30 languages across the world.
- 40 East African businesses pledged to ban the sale of single-use plastic bottles/straws and one Kenyan county government immediately committed to close down its biggest dumpsite.
- During the 500km, all of the team took part in collecting over 120 water samples to test for Micro-Plastics and Micro-Fiber's, they developed simple tools and techniques for analysis and shared this data with the wider scientific community.

Figure 12. Images of the school children and Mr Siim Kiisler onboard the Flipflopi.

In Zanzibar, the team was honoured to be joined by the President of the United Nations Environment Assembly, Mr Siim Kiisler commented that “The Clean Seas - Flipflopi Expedition inspires citizens from Africa and around the world to become more aware of one of the most urgent environmental issues that we face”.

Following the completion of the Clean Seas expedition, the Flipflopi boat was the centre piece exhibit at the UN Environment Assembly, in Nairobi Kenya (11th to 15th March 2019), a forum that brought together more than 150 ministers of environment. The assembly is the world’s highest-level decision-making body on the environment.

7.1 Further research

The researchers are working to further refine the waste plastic recycling processes described in this paper. This will enable the production of a large ocean-going dhow that will travel from Lamu in Kenya to Cape Town in South Africa in 2021.

Additionally, further work is being undertaken to explore how these techniques and methods can be applied to other areas of dhow production such as the sail and mast. Work is also being carried out to embed these processes into the dhow making industry and to explore the use of recycled plastic as a material for boat repairs.

7.2 The big picture

It should be noted that the innovative construction of the dhow only highlights a limited level at which the success of traditional design interventions can be judged in that it impacts on an existing situation rather than addressing the root cause of a global waste problem. Whilst the boat building project is raising awareness of the pressing need for the adoption of sustainable practices, the growth of a circular economy requires the enrolment of all stakeholders worldwide, as Martinez and English (Martinez, 2015) find “the key to a fundamental change in approach does not reside solely with designers” however “the use of relational and systems thinking tools to facilitate sustainable design throughout business and society, could prove to be far more valuable and effective”.

The build of the dhow only acts as a tangible vessel for spreading the core message of the project, the overriding vision for the collaboration between The Flipflopi Project and the UN Environment’s Clean Seas campaign is to raise awareness of the value in the materials we use every day and provide a platform and opportunity for significant change to be made by engaging all stakeholders, raising awareness of the circular economy throughout the global community, which in turn would prevent the plastics from entering the oceans in the first place.

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Stuart English: A specialist in design innovation, Dr. Stuart English is Director of Enterprise and Engagement at Northumbria University, his work on relational problem framing has initiated new methods, new products and new IP through an inclusive approach based on design-led enterprise.

Ali Skanda: The co-founder of the Flipflopi Project. A renowned master Dhow Fundi (boat-builder), his work can be found in museums and collections around the world including the Smithsonian National Museum, passionate about preserving the health of the oceans and coastal peoples worldwide.

Leonard Schurg: The lead engineer on the Flipflopi Project, he engineers the bridge between traditional craftsmanship and modern materials. He is dedicated to turn the tide around and create a sustainable balance between us and our hosting biosphere.

Katharina Elleke: The design lead on the Flipflopi Project, she also works on solutions for environmental and social issues globally. She is a key member of Precious Plastic who provide tools and knowledge to people how boost plastic recycling worldwide.

Ben Morison: The founder of the Flipflopi Project. He started the project as a direct response to the alarming degradation of the African coastline by waste plastics. He is a passionate speaker and communicator of environmental issues and finding solutions.

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Acknowledgement: Regeneration Africa, Benson Gitari, Northumbria University and The Flipflopi Project Foundation.